DIVISION S-5—PEDOLOGY

Microclimate and Pedogenic Implications in a 50-Year-Old Chaparral and Pine Biosequence

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ABSTRACT

Vegetation, which is generally considered a co-variable controlled by climate in studies of pedogenesis, can itself alter the balance of soil-forming processes by modifying the microclimate. The chaparral and pine biosequence at the San Dimas Experimental Forest (SDEF) in southern California offers an opportunity to determine the effect of individual species on soil microclimate and related soil properties. Soil temperature and moisture were monitored under pure stands of Coulter pine (*Pinus coulteri* B. Don), chamise (*Adenostoma fasciculatum* Hook. and Arn.), and scrub oak (*Quercus dumosa* Nutt.). Despite the appreciable differences in soil morphology that have evolved under pine compared with oak, the microclimates created by the dense canopies and thick litter layers (7–10 cm) of these two vegetation types were similar. Average monthly soil temperatures within the top 65 cm ranged from about 8 to 20°C under pine and 7 to 18°C under oak. Average monthly water contents ranged from 8 to 32% (by volume) under pine and 6 to 32% under oak. In contrast, average monthly soil temperatures within the top 65 cm under chamise ranged from 6 to 23°C and average monthly water contents were 6 to 36%. Diurnal variation in soil surface temperature under chamise was much more pronounced than under oak and pine because of the relatively open canopy and thin litter layer. Microclimate created by chamise may play an important role in the decomposition rate of litter, but appears to have little influence on soil processes occurring within the mineral soil. Soil macrofaunal communities appear to have a greater effect than microclimate in causing the divergent soil morphologies under oak and pine.

T HE ULTIMATE CHARACTERISTICS of a soil can conceptually be viewed as a result of the balance of soil-forming processes across time (Simonson, 1959). The dominant soil-forming processes result from interactions between the five soil-forming factors as described by Jenny (1941). Of the five soil-forming factors, organisms have been one of the most difficult to quantify because of the covariance of vegetation with other factors such as climate and parent material (Jenny, 1941). Vegetation can alter the balance of soil-forming processes through both direct and indirect mechanisms. Directly, plant roots create pores and alter the chemical, physical, and hydraulic properties of soil. Indirectly, vegetation may select for soil fauna through litter palatability, and alter the energy balance creating unique microclimates.

Vegetation communities, or even single trees, create microclimates through shading of the earth by the canopy (Buol et al., 1997), restriction of wind movement (Campbell, 1977; Rosenberg et al., 1983), and transpirational water loss (Kelly et al., 1998). The effect of vegetation on soil temperature depends on density, height, and color of the vegetation (Buol et al., 1997) and is therefore species dependent. Another important factor, determined in part by plant characteristics, is litter layer thickness. The insulating effect of litter causes surface temperatures to remain cooler during daylight hours and warmer at night compared with bare soil (Buol et al., 1997). Mulches of vegetative origin can dampen the diurnal fluctuations in soil temperature considerably because they have low thermal conductivity (Hanks et al., 1961; Barkley et al., 1965). Microclimates are important to understand since they may influence the activities of soil organisms (Coleman and Crossley, 1996) that regulate important soil processes such as nitrogen transformations, decomposition, and mineral weathering.

Although the importance of vegetation type as a soil-forming factor has long been noted, the rarity of true biosequences has limited our ability to quantitatively study it. The biosequence of lysimeter soils at the SDEF provides a unique opportunity to study the effects of vegetation on soil properties. This biosequence has been extensively studied, and differences in soil morphology (Graham and Wood, 1991), physical and hydraulic properties (Graham et al., 1995; Johnson-Maynard et al., 2002), C and N accumulation (Ulery et al., 1995), mineralogy (Tice et al., 1996), base cation biogeochemistry (Quideau et al., 1996), and decomposition rates (Quideau et al., 1998, 2000, 2001; Feng et al., 1999) have been documented under the different vegetation types. Although these studies have shown that vegetation can exert a significant influence over soil processes and properties across relatively short time spans, it is unknown whether these changes have resulted from direct or indirect effects of the plants. The objective of this study, therefore, is to determine if vegetation has directly caused divergent pathways of soil pedogenesis, or if the indirect effects of microclimate and selection of soil organisms are more important.

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Abbreviations: MAST, mean annual soil temperature; SDEF, San Dimas Experimental Forest; TDR, time domain reflectometry.

MATERIALS AND METHODS

Environmental Setting

The SDEF is a U.S. Forest Service watershed research laboratory located in the San Gabriel Mountains, about 56 km northeast of Los Angeles, CA. The climate is a mediterranean type with warm, dry summers and mild, wet winters. The 64-yr mean annual precipitation at Tanbark Flat, located 200 m southeast of the lysimeter installation within the SDEF, averages 72.3 cm (San Dimas Experimental Forest, 2002), most of which falls between December and March. Rainfall totals received at Tanbark Flat are variable, a characteristic of mediterranean ecosystems (Mooney and Dunn, 1970). Total precipitation during the first year of the study (1997) was near average (71 cm). In Year 2 (1998), the total precipitation was approximately double that of the long-term average (137 cm). The long-term mean annual air temperature at Tanbark Flat is 14.4°C (Dunn et al., 1988). The average minimum and maximum air temperatures, calculated from 67 yr of data, are 8.5 and 21.7°C (San Dimas Experimental Forest, 2002). During the first year of this study (1997), the minimum temperature was 8.5°C and the maximum was 22.3°C. In 1997, the minimum and maximum temperatures were 8.0 and 20.5°C.

In 1937, a series of five pits measuring 5.3 by 5.3 by 2.1 m deep were excavated at an elevation of 830 m at Tanbark Flat, SDEF. The excavated material, which was derived from the weathering of diorite, was homogenized and sieved to remove rock fragments and aggregates >19 mm in diameter before being returned to the pits. During the filling of the pits, samples were taken from every 7.5-cm fill increment and archived, providing knowledge of the initial state of the system. The purpose of these earthen-walled pits, referred to as "lysimeters," was to monitor changes in water availability under different plant communities (Patric, 1961a, 1961b). After allowing for a settling period of 3 yr (1937–1940), excess fill material was removed from the surface and the lysimeters were planted with an annual grass [*Bromus mollis* L. (=*B. hordeaceus* subsp. *hordeaceus*)]. Six years later (1946), the grass was burned and replaced with monocultures of native species including chamise, scrub oak, and Coulter pine. The design of the lysimeters minimized variation of all environmental conditions except vegetation (Colman and Hamilton, 1947; Patric, 1961a). The physical arrangement of the lysimeters with the planted species is shown in Fig. 1. In 1960, the chamise stand was completely burned in a wildfire. During the same fire, the scrub oak foliage was slightly burned but the litter layer was unaffected and the pine vegetation did not burn at all (Dunn et al., 1988; Feng et al., 1999). Since the stands were not burned between 1960 and 1998, all communities were mature and producing microclimates that reflect maximum canopy and litter layer development. Pine, oak, and chamise were selected for this study because a more complete record of stand and soil characteristics are available for these three species.

Vegetation

The term chaparral refers to the woody, sclerophyllous, fire-adapted vegetation occurring in zones of the southwestern USA that are characterized by a mediterranean climate (Steward and Webber, 1981). Two of the species used in this study, scrub oak and chamise, are dominant chaparral species in southern California (Hanes 1981; Steward and Webber, 1981). Chamise shrubs have ascending branches with narrow, needle-like leaves that are approximately 1 to 2 cm in length (Poole et al., 1981). The canopy height of chamise chaparral is typically 1 to 2 m (Hanes, 1977). Like chamise, scrub oak has ascending branches, but is a broad-leafed species with a much denser
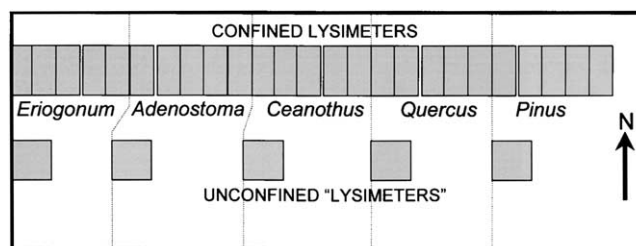

Fig. 1. Diagram of the lysimeter installation at the San Dimas Experimental Forest. The large, earthen-walled pits (referred to as unconfined lysimeters) used in this study are 5.3 by 5.3 by 2.1 m deep. The indicated species were planted on each lysimeter as well as surrounding buffer areas (indicated in white). *Adenostoma*, *Quercus*, and *Pinus* were used in this study. Figure modified from Patric (1961b).

canopy that almost reaches the ground. Scrub oak stands are commonly between 2 and 4 m in height (Hanes, 1977). Coulter pine is found at elevations of between 600 and 2150 m (Wright, 1966) and is commonly associated with chaparral. Coulter pine has a straight bole that is bare for the first 3 m, long needles (20–36 cm), and cones that are among the largest produced by pines (Pinchot, 1908). Coulter pines are relatively small, reaching heights of between 16 and 20 m (Pinchot, 1908).

Chaparral species commonly have a dual or dimorphic root system with a large lateral component to exploit surficial moisture and a deeply penetrating component to access water at depth during summer drought (Hellmers et al., 1955). Scrub oak has the most extensive rooting system of chaparral species, with roots penetrating down to 9 m in some locations (Hellmers et al., 1955). Chamise has a rooting pattern that is similar to that of scrub oak, but is much less extensive. The maximum rooting depth of chamise is typically 2 to 4 m (Hellmers et al., 1955; Kummerow et al., 1977). Coulter pine, which is one of the most drought-tolerant pines in southern California, is relatively deep rooted. Mature Coulter pine trees have been reported to have roots that extend 3 m into fractured bedrock (Wright, 1966, 1968).

Field Measurements

To minimize disturbance to this long-term study, pedons that were originally sampled in 1987 under each vegetation type were reopened and disturbed material was removed until a fresh face was exposed. Soils were described and sampled using standard methods (Soil Conservation Service, 1984). Three replicate time domain reflectometry (TDR) soil moisture probes were placed horizontally at the 10-, 35-, and 65-cm depths (measured from the mineral soil surface) in different faces of one pedon under each vegetation type. Temperature probes were placed in the same pedon, away from the influence of the TDR probes, at 0 (directly beneath the litter layer), 10, 35, 50, and 65 cm. A data logger recorded hourly average soil temperature readings. The TDR waveforms were recorded hourly during each rainy season and three times a day during dry periods. Before installation, TDR probes were calibrated with soil collected on-site packed in columns to bulk densities similar to those found in the biosequence soils. Entire TDR waveforms were downloaded and analyzed by a program developed at the USDA Salinity Laboratory in Riverside, CA. Volumetric water contents were calculated from gravimetric samples taken periodically to ensure that the TDR probes were operating properly. A weather station at Tanbark Flat has continually monitored air temperature, humidity, wind speed and direction, and rainfall since 1933.

Table 1. Morphological, chemical, and physical data from pedons under pine, oak, and chamise.

Horizon	Depth	Structure†	Roots‡	OC	C:N	Total porosity§
	cm			%		%
		Pine				
Oi1	10–6	Fresh pine needles, twigs, some grass				
Oi2	6–4	Partially decomposed pine needles				
Oe	4–0	Mostly decomposed pine needles				
A	0–1	2msbk	3vf,2f	3.15	19.8	n.d.
BAt	1–10	2msbk	2vf&f, 1m&co	0.63	15.4	41
Bt	10–20	1msbk	1vf-co	0.49	15.9	41
BCt	20–35	M	1vf-m	0.49	12.7	41
C1	35–50	M	1vf-co	0.29	17.2	39
C2	50–65	M	1vf-co	0.24	16.3	40
		Oak				
Oi	7–0	Fresh oak leaves, twigs, worm casts, and some pine needles				
A	0–8	3fsbk→3fgr (worm casts)	2vf&f	2.49	16.6	52
AC	8–20	1msbk→m	2vf-m	0.54	16.7	43
C1	20–35	M	1vf&co	0.26	13.4	42
C2	35–50	M	1vf&co, 2f&m	0.23	13.4	40
C3	50–65	M	1vf&co, 2f&m	0.20	11.8	40
		Chamise				
Oi	3–0	Fresh chamise leaves, twigs, and worm casts				
A1	0–1	3msbk→3fgr (worm casts)	1vf	4.38	20.0	n.d.
A2	1–7	2msbk	2vf&f	0.99	16.0	46
AC	7–20	1msbk	2vf&f, 1m	0.42	14.3	41
C1	20–35	M	2vf-m	0.27	12.9	40
C2	35–50	M	2vf-m	0.21	11.6	40
C3	50–65	M	2vf-m	0.25	12.8	40

† 1 = weak, 2 = moderate, 3 = strong, f = fine, gr = granular, m = medium, M = massive, sbk = subangular blocky, → = parting to.
‡ 1 = few (<1 dm⁻²), 2 = common (1–5 dm⁻²), 3 = many (>5 dm⁻²), co = coarse, g = fine, m = medium, vf = very fine.
§ Calculated from bulk density [determined with Saran (Dow Chemical Co., Midland, MI) coated clods] assuming particle density of 2.65 Mg m⁻³; n.d. = not determined.

RESULTS

Soil Morphology and Pedogenic Processes

Morphologic characteristics were identical to the published descriptions of Graham and Wood (1991) under chamise and pine and will only be considered briefly here. The soil formed under pine had a 10-cm-thick O horizon with distinct Oi1, Oi2, and Oe components (Table 1) and a 1-cm-thick A horizon. Below the A horizon, there was an increase in clay content from the 1- to 35-cm depth and the presence of thin clay films that were bridging sand grains and lining pores. Soil supporting chamise had a 3-cm-thick Oi horizon, a 1-cm-thick A1 horizon that was approximately 50% earthworm casts. The A2 horizon that extended from 1 to 7 cm contained approximately 10% earthworm casts that were primarily found within burrows. Few, thin, clay films were described along vertical settling cracks.

Soil morphology under oak was similar to the 1987 descriptions with minor differences found within the A horizon. The average A horizon depth under oak was 8 cm, a 1-cm increase since the 1987 sampling. There were no increases in clay content with depth under oak and no clay films were described.

Soil Temperature

Seasonal fluctuations and ranges of soil temperatures at each depth were similar among the vegetation types, ranging from 8 to 20°C under pine and 7 to 18°C under oak (Fig. 2a,b). Soil temperatures in the top 65 cm under chamise tended to be slightly cooler during the winter and warmer in the spring and summer than under oak

and pine, ranging from 6 to 23°C (Fig. 2c). For the purposes of clarity, temperatures at only three depths (0, 10, and 50 cm) are shown in Fig. 2.

One spring month (29 May to 29 June 1997) was selected to display soil temperature dynamics under the three vegetation types. During this period, air temperatures ranged from about 14 to 33°C (Fig. 3). Under chamise, maximum temperatures at the mineral soil surface (below 3 cm of litter) occurred at nearly the same time as the maximum air temperatures, and were often nearly equal in magnitude (Fig. 3). Maximum temperatures under oak and pine were much lower than maximum air temperatures (Fig. 3).

Changes in soil temperature with time (t) and depth (z) can be approximated as a sine wave with the following equation (Jury et al., 1991):

$$T(z,t) = T_A + A \exp(z/d) \sin(\omega t + z/d)$$

where T = temperature at depth z and time t, T_A = annual average temperature, A = amplitude of the wave (decreases with depth), and d = damping depth [dependent on soil physical properties and the angular frequency (ω) of the surface change].

At any given depth (z), the amplitude of the temperature fluctuation decreases relative to the amplitude at the surface by a factor $e^{z/d}$. Damping depth refers to the depth at which A decreases to $1/e$ of the amplitude at the soil surface, and is dependent on soil properties and climate (Hillel, 1982). The damping depth will therefore be shallower for a soil exhibiting large temperature fluctuations at the soil surface. Graphical analysis of soil temperature data is shown in Fig. 4. In this method,
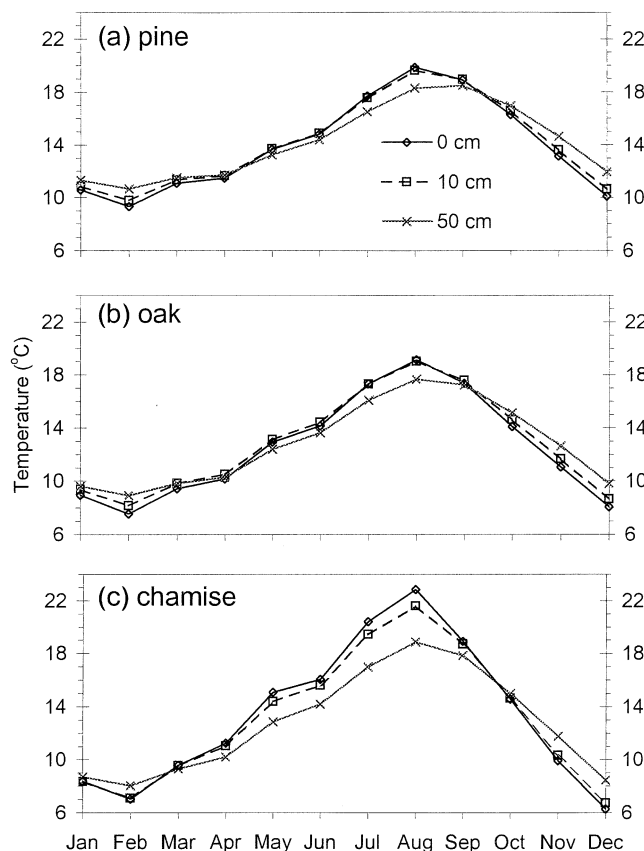
Fig. 2. Mean monthly soil temperature at selected depths from 1997 and 1998 data collected under (a) pine, (b) oak, and (c) chamise.
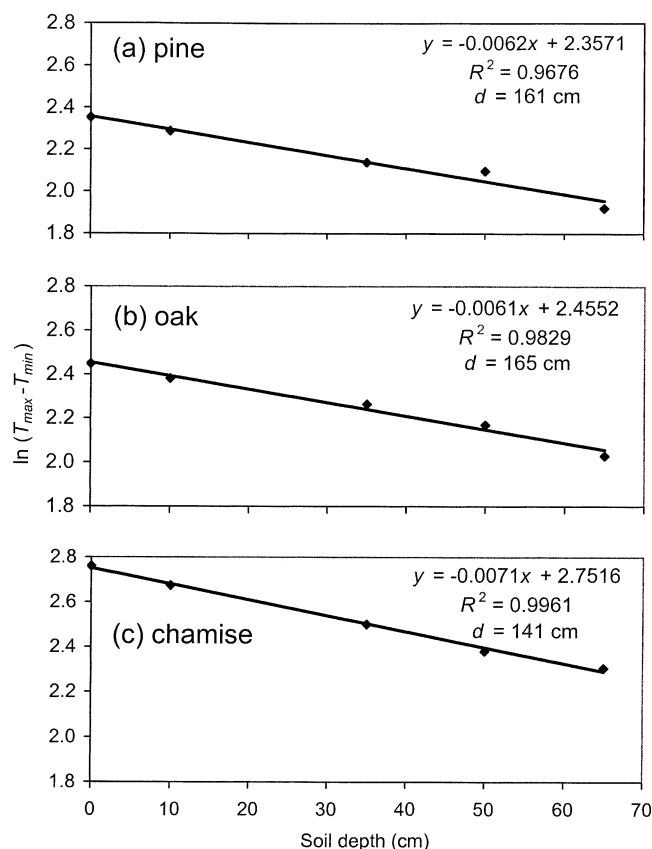

Fig. 4. Calculation of the annual damping depth (cm) under (a) pine, (b) oak, and (c) chamise, by the relationship $\Delta T = \ln(2A) + z/d$ (Jury et al., 1991), where A = amplitude, z = depth, and d is the inverse slope of the regression line.

linear regression is used to determine d. The inverse of the slope of the regression line [of the form $\ln(\Delta T) = \ln(2A) + z/d$] is d (Jury et al., 1991). Annual fluctuation of temperature is damped out (reduced to $1/e$ of the amplitude at the surface) at 165 cm under oak, 161 cm under pine, and 141 cm under chamise (Fig. 4). The concept of damping depth is used to describe the attenu-

ation of heat with depth and does not necessarily indicate a lack of daily or annual variation in soil temperature.

Soil taxonomy recognizes 50 cm as the depth where daily temperature fluctuations are hardly measurable,
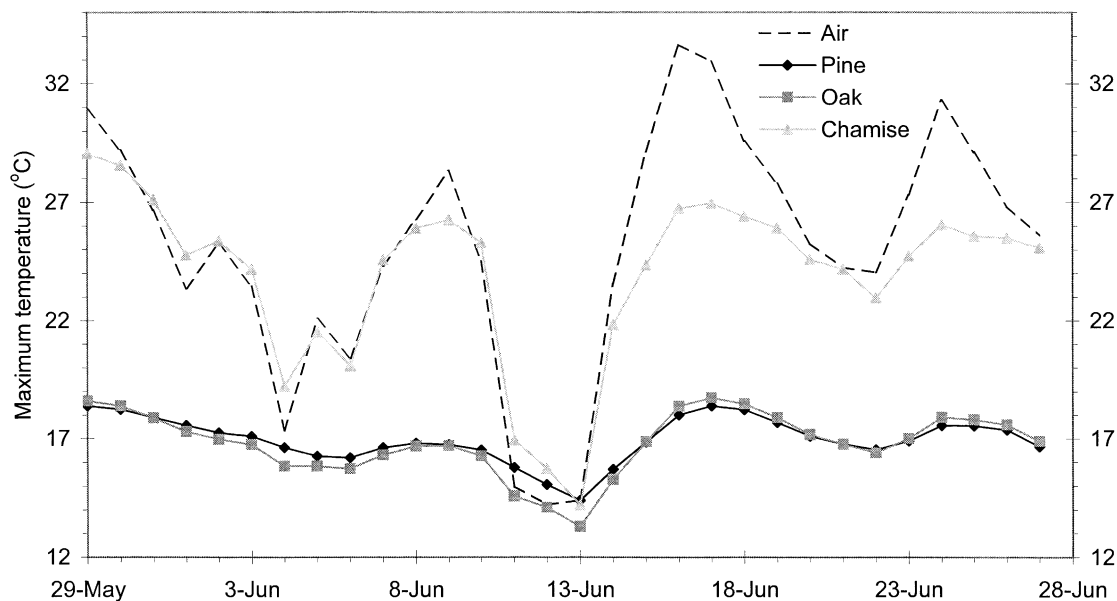

Fig. 3. Daily maximum air temperatures and mineral soil surface temperatures taken directly under the litter layer of pine, oak, and chamise.

Table 2. Mean annual soil temperature for two years of data (1997 and 1998) at each depth under chamise, oak, and pine.

Depth	Chamise	Oak	Pine
cm		°C	
10	13.1	12.9	14.1
35	13.3	12.7	14.2
50	12.7	12.8	14.1
75	13.2	12.9	14.5

and 10 m as the depth at which annual cycles are virtually eliminated (Soil Survey Division Staff, 1993). These depths are used as a tool to compare all soil types under different climates and therefore were chosen to encompass a broad range of soil types and climates while damping depth is specific to each soil. While damping depth is used to describe the attenuation of heat with depth, measurements of mean annual soil temperature (MAST) are used to define thermal regimes. The MAST values based on measurements taken at a depth of 50 cm were 12.7°C under chamise, 12.8°C under oak, and 14.1°C under pine (Table 2) across the 2 yr of this study.

Soil Moisture

Average monthly soil moisture values ranged from 8 to 32% under pine (Fig. 5a) and 6 to 32% under oak (Fig. 5b). The soil under chamise tended to reach slightly higher water contents and ranged from 6 to 36% (Fig. 5c) across the 2-yr study period. Water storage data show that the water held within the upper 65 cm
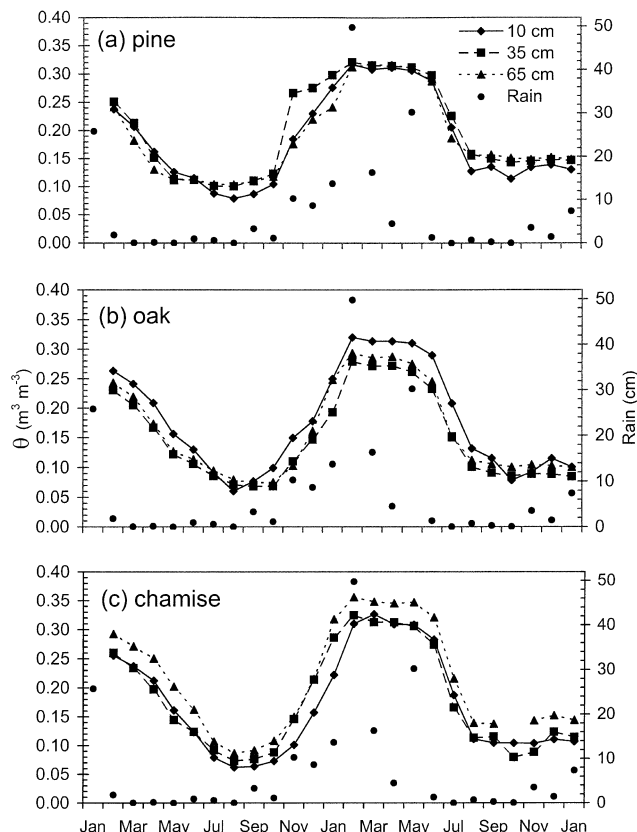

Fig. 5. Monthly average volumetric water content with depth and the amount of rain (cm) received during each month for 1997 and 1998 under (a) pine, (b) oak, and (c) chamise.

of soil decreases quickly following the end of the rainy season under each vegetation type (Fig. 6). Chamise tended to store slightly more water during the spring, but by the end of July of both 1997 and 1998, all soils had similar water contents.

DISCUSSION

Soil Temperature

Data collected from 1952 to 1959, when canopy density ranged from 22% for Coulter pine to 87% for scrub oak (Patric, 1974), show that the MAST measured at 61 cm was 13.6°C under oak and 16.1°C under pine (Qashu and Zinke, 1964). On the basis of temperature values taken during that 7-yr-period, the soil temperature regime under oak was mesic while under pine it was thermic (Graham and Wood, 1991; Soil Survey Staff, 1998). During the 30-yr period since the Qashu and Zinke study, the complete closure of canopies and development of litter layers have modified the soil temperature regimes so that all three soils are now mesic (Soil Survey Staff, 1998), with MAST values ranging from 12.7 to 14.1°C (Table 2). These data indicate that the influence of vegetation-induced microclimate on soil processes may have been greater in the earlier stages of pedogenesis. They also highlight the importance of understanding how plant communities, and therefore microclimate, change with age or succession especially in modeling the outcomes of disturbance on ecosystem processes.

Greater fluctuations of soil temperature at the surface under chamise (Fig. 3) are due to the shrub's morphology. Chamise has a relatively sparse canopy (low leaf area index) with many intertwined, bare branches. Chamise typically achieves only 80% shrub coverage by 50 yr, as opposed to 100% coverage by 50-yr-old scrub oak stands (Hanes, 1977). At the SDEF lysimeters, chamise (70 Mg ha^{-1}) has less aboveground biomass than oak (290 Mg ha^{-1}) and pine (304 Mg ha^{-1}) (Milone, 1994) and presumably a lower leaf area index due to acicular leaves. Lower leaf area results in less attenuation and reflection of radiant energy by the canopy and more energy reaching and leaving the surface of the soil (Rosenberg et al., 1983).

Another important characteristic in regulation of soil temperature is the thickness and character of the litter layer. A mulch layer usually has a thermal conductivity much lower than a mineral soil and therefore gains and loses heat more slowly (Hanks et al., 1961). The chamise soil had a 3-cm-thick litter layer compared with a 7-cm layer under oak and a 10-cm layer under pine (Table 1). The chamise litter layer was composed of relatively small (approximately 1–2 cm in length) needle-like leaves. Because of their shape and small size, the chamise needles should achieve relatively tight packing, resulting in less entrapped air and higher thermal conductivity compared with litter under oak and pine. Although heat conduction was not directly measured, the relatively thin and densely packed chamise litter layer should efficiently conduct heat downward, compared with the oak
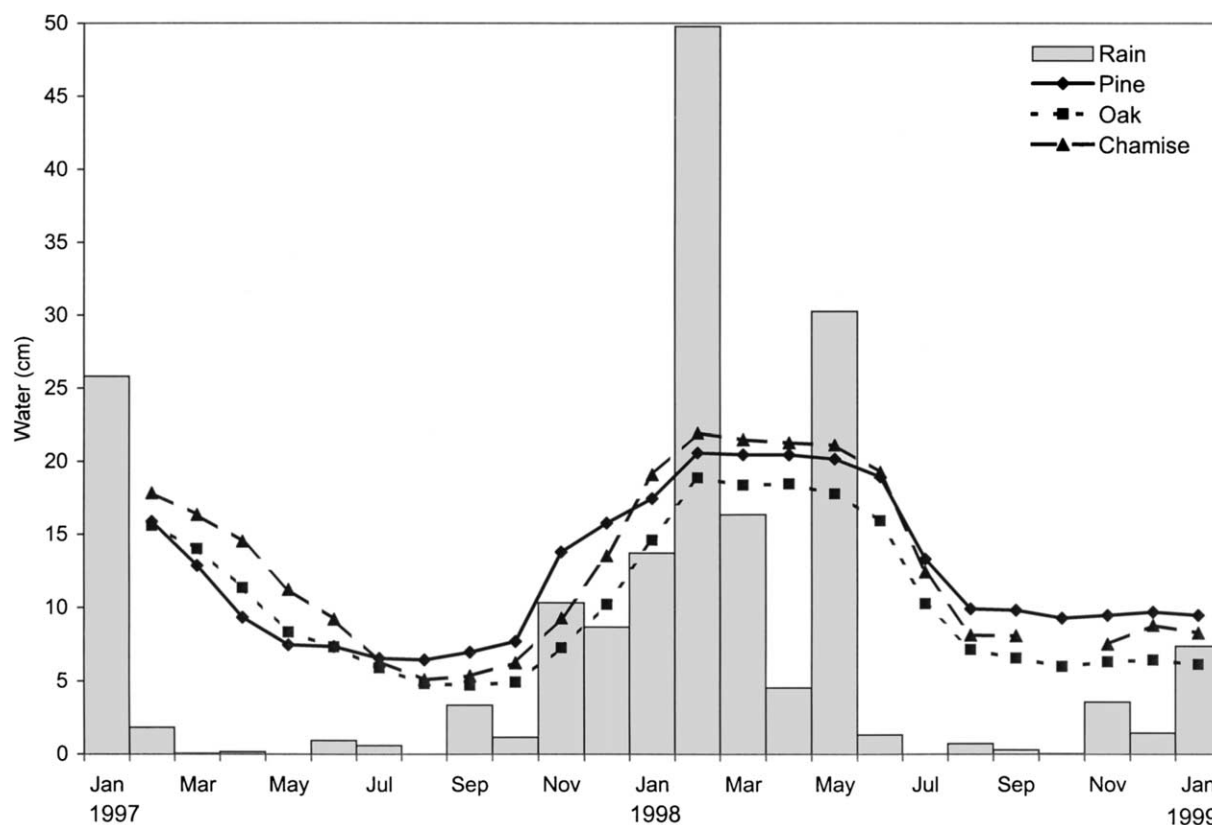
Fig. 6. Monthly precipitation and water storage within the top 65 cm of soil under pine, oak, and chamise for 1997 and 1998.

and pine litter layers, allowing the mineral soil surface to warm quickly.

During spring, diurnal changes of 14°C occurred at the mineral-soil surface under chamise compared with 4°C diurnal change under oak and pine (Fig. 3). Diurnal fluctuations of 15 to 18°C have been measured at a depth of 5 cm in temperate regions (Paul and Clark, 1996). Although the 14°C diurnal change is not unusually large when compared with other temperate sites, the microclimate under chamise represents a less thermally moderated environment than the microclimates under oak or pine.

The MAST at each depth studied varied by <2°C among the three vegetation types (Table 2). The large flux of energy between the mineral soil surface under chamise and the atmosphere results in a relatively low net heat flux downward, indicating that the modification of soil temperature by chamise is largely a surface phenomena. This is consistent with the observation that rapidly changing surface temperatures do not penetrate as deeply into the soil as slowly changing temperatures (Jury et al., 1991).

Calculated damping depth values (Fig. 4) also indicate that heat is attenuated more quickly with depth under chamise than under oak and pine. Soil temperature and damping depth values indicate that alteration of the energy balance by vegetation cannot currently differentiate pedogenic processes under oak and pine, where soil thermal regimes are nearly identical. Under chamise, vegetation is less effective at moderating soil temperature fluctuations near the surface, which may especially impact soil processes in O and A horizons, such as litter decomposition.

Soil Moisture

The temporal distribution of soil moisture is closely related to rainfall (Fig. 5, 6). The rate of water loss under each vegetation type is best demonstrated in 1997, as opposed to 1998 when soil moisture levels were higher than expected because of spring rains. The soil under pine rapidly dried, losing 53% of the stored water in the top 65 cm of soil between February and May, the most active period of growth for chaparral species. During this same time period and depth, soil moisture under oak was depleted by 47%, while the soil under chamise lost only 37%. The rapid depletion of soil moisture by evapotranspiration following the cessation of the rainy season in January 1997 and May 1998 (an El Niño year) (Fig. 6) demonstrates the reliance of these chaparral species on water stored during the wet season.

Water contents and storage tended to be higher during the growing season within the soil supporting chamise (Fig. 5 and 6), a plant that is adapted to warm, dry, south-facing slopes in southern California (Hanes, 1977). More water was stored under chamise despite a higher evaporative demand caused by higher soil surface temperatures, which in turn are caused by meager shading and a thin litter layer. Another factor in the hydrologic budget is transpiration. Transpiration rates for chamise in southern California chaparral have been shown to be half those of oak (Miller et al., 1981).

Transpiration rates were lower in chamise stands compared with those in mixed chaparral in Echo Valley, CA (Poole et al., 1981). Although the evaporative demand was higher under chamise, lower transpiration rates resulted in overall less depletion of soil water. Differences in water balances within these biosequence soils are largely controlled by transpiration, which varies by species, rather than evaporation. Maintenance of low transpiration rates, a plant survival strategy in dry climates, may lead to more water available for soil processes such as leaching (during wet years), mineral weathering, and decomposition of organic matter.

Microclimate and Pedogenic Processes

Despite similar temperature and moisture regimes, the soils formed under oak and pine show the most contrasting morphologies across the biosequence. The soil under pine is an Alfisol with a weakly developed argillic horizon and a thin (1-cm-thick) A horizon, while the soil under oak is an Entisol trending toward a Mollisol (Graham and Wood, 1991). As evidenced by macro- and micromorphology data reported by Graham and Wood (1991), the transfer, or eluviation and illuviation, of silicate clay is the dominant soil-forming process under pine. Illuviation is favored by (i) the presence of water which serves as the means of transportation, (ii) the lack of burrowing macrofauna that disrupt horizonation; and (iii) the presence of organic acids that alter the surface charge properties, thereby encouraging dispersion. The coating of clay particles with organic materials has been reported to increase colloidal stability and enhance dispersion (Tipping and Higgins, 1982; Gibbs, 1983; Kaplan et al., 1993; Kretzschmar et al., 1993). Due to the experimental design of the lysimeters, it is impossible to determine if the release of organic acids from litter decomposition (direct effect), or the absence of burrowing fauna (indirect effect) has a larger influence on the formation of clay-enriched horizons. The fact that the oak and pine have similar microclimates suggests, however, that these factors are much more important than the amount of water available for leaching.

Under oak, the addition of organic matter and subsequent formation of a dark-colored A horizon through the process of melanization (Buol et al., 1997) are the dominant soil-forming processes. The average A horizon thickness was 8 cm, a gain of 1 cm since the 1987 sampling. If the entire period of soil genesis is considered (1946–1997), the average rate of A horizon formation is 0.16 cm yr^{-1}. If the A horizon continues to develop at this rate, the soil should have a dark, 25-cm-thick A horizon and be classified as a Mollisol in approximately 109 yr. Melanization is a dominant process in grasslands and is favored by the addition of large amounts of organic material via roots. Melanization is of less importance in most forested ecosystems where the addition of organic material is predominately on the surface with little incorporation into the mineral soil. Melanization, therefore, can be favored by the production of large amounts of belowground biomass or by the rapid incorporation of surface organic matter into the soil by soil organisms. Litter biomass under oak and pine are very similar, ranging from 11.0 Mg ha^{-1} under oak to 11.2 Mg ha^{-1} under pine. Pine also has a higher number of very fine and fine roots in the A horizon (Table 1) and medium and course roots within the top 10 cm (Johnson-Maynard et al., 2002) as compared with oak. Biomass data, therefore, show that differences in total above- and belowground biomass are not likely responsible for the formation of distinctly different O, A, and B horizons under oak and pine. Measurements of ^{14}C and C:N ratios indicate that pine litter undergoes a higher degree of decomposition at the surface, while oak litter is quickly incorporated into the mineral soil (Quideau et al., 2001). Litter incorporation is increased by the action of macrofauna such as earthworms (Lee, 1985). A relatively large population of exotic earthworms (*Aporrectodea caliginosa* and *A. trapezoides*) was found under scrub oak, while earthworms were virtually absent under pine. The activity of these opportunistic earthworms, which feed on soil associated with organic matter (Bouchè, 1977) as well as surface litter (Lee, 1995), serves to increase the incorporation and decomposition of oak leaf litter by fragmenting it and physically mixing it into the mineral soil. Under oak, the indirect influence of the large earthworm community is likely responsible for the high degree of melanization.

Under chamise, the presence of clay films and the A horizon thickness indicate that both melanization and illuviation are active. Morphologically speaking, the soil under chamise, with A1 and A2 horizons equaling 7 cm and evidence of illuviation of clay, is intermediate between the soils formed under oak and pine. Microclimate data indicate that the major difference among the three vegetation types is the large flux of energy that must occur at the surface under chamise. The less thermally moderated environment under chamise may influence near-surface processes such as litter decomposition. The C:N ratio, in part, determines the quality of litter to serve as a food source and can be used as an indicator of decomposition. As litter is decomposed, C is lost from organic material as CO_2 (g) while N accumulates, resulting in a decrease in the C:N ratio of the remaining material (Swift et al., 1979, p. 372). The C:N ratios of chamise (44) and oak (39) foliage are lower than that of pine (57) (Quideau et al., 1998). Despite similar C:N ratios for foliage, the C:N ratio of chamise litter (32.9 $\pm$ 1.4) is lower than that of the oak litter (44.6 $\pm$ 3.9). The larger C:N ratio decrease from foliage to litter material under chamise indicates a higher degree of decomposition. The C:N ratios for the A horizons are similar, ranging from 16.6 under oak to approximately 20.0 under chamise and pine (Table 1). Differences between C:N ratios among the vegetation types are larger for the foliage and litter than for the soil. This reinforces the conclusion that microclimate differences under chamise are largely restricted to the surface (O horizon) and do not strongly alter the decomposition environment within the mineral soil. On the basis of these results, we interpret that differences in microclimate as well as perhaps litter quality serve to increase litter decomposition under chamise relative to oak and

pine. Macrofaunal activity cannot be responsible for the higher decomposition values observed under chamise relative to under oak since there are fewer earthworms under chamise (Graham and Wood, 1991; Johnson-Maynard et al., 2002).

CONCLUSIONS

In the San Dimas biosequence, the formation of distinctly different O and A horizons under oak and pine is probably more due to the action of earthworms, or their absence, than microclimate. Since the palatability of litter determines the distribution of earthworms, vegetation type indirectly controls incorporation and decomposition rates through the influence of litter composition rather than through its effect on microclimate. Although it is impossible, given the current data, to separate the effects of the absence of earthworms and production of organic acids under pine, either or both of these factors are more important influences on the illuviation of silicate clay than is microclimate. Under chamise, the importance of microclimate on soil processes appears to be restricted to the near-surface soil, where it may influence the rate at which litter decomposes. The influence of microclimate on soil processes under chamise should be further investigated, considering its widespread distribution in the southwestern USA.

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